



Real-World Activity Patterns of Heavy-Duty Vehicles and Their Implications on In-Use Emissions

Kanok Boriboonsomsin

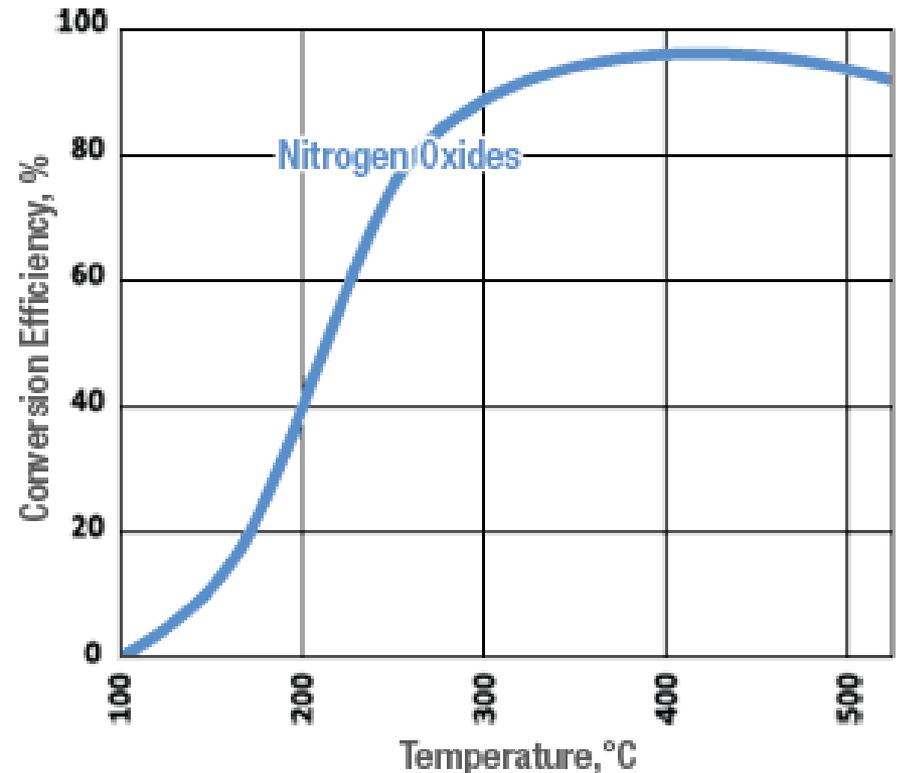
University of California at Riverside

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Background (1)

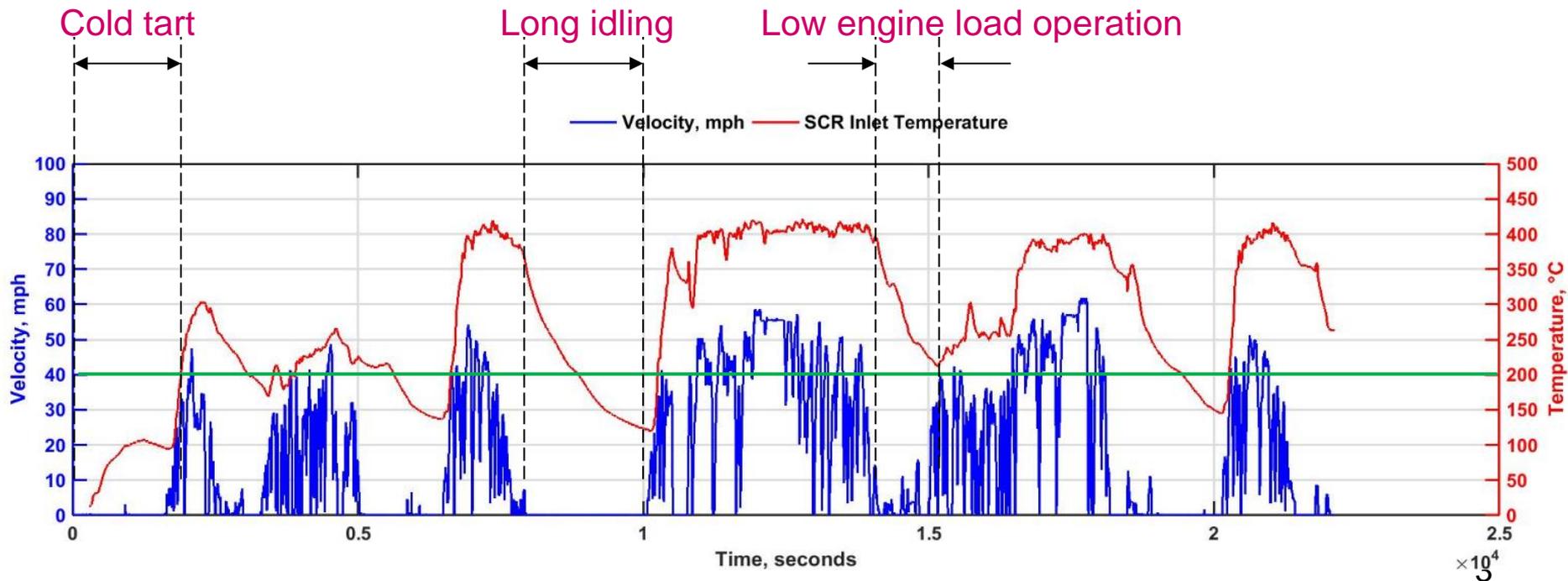
- Heavy-duty vehicles serve a variety of vocations.
 - Different operational requirements resulting in different vehicle activity patterns.
- Selective Catalytic Reduction (SCR) is used in most heavy-duty diesel engines to meet 2010 nitrogen oxides (NO_x) emission standards.
 - Typically, SCR needs to be at high temperature before significant NO_x reduction is achieved.





Background (2)

- There are real-world situations where SCR temperature may not be at the optimum NO_x conversion efficiency.
 - Cold start, long idling, low engine load operation
 - Fraction of these situations in HDV operation varies by vocation.



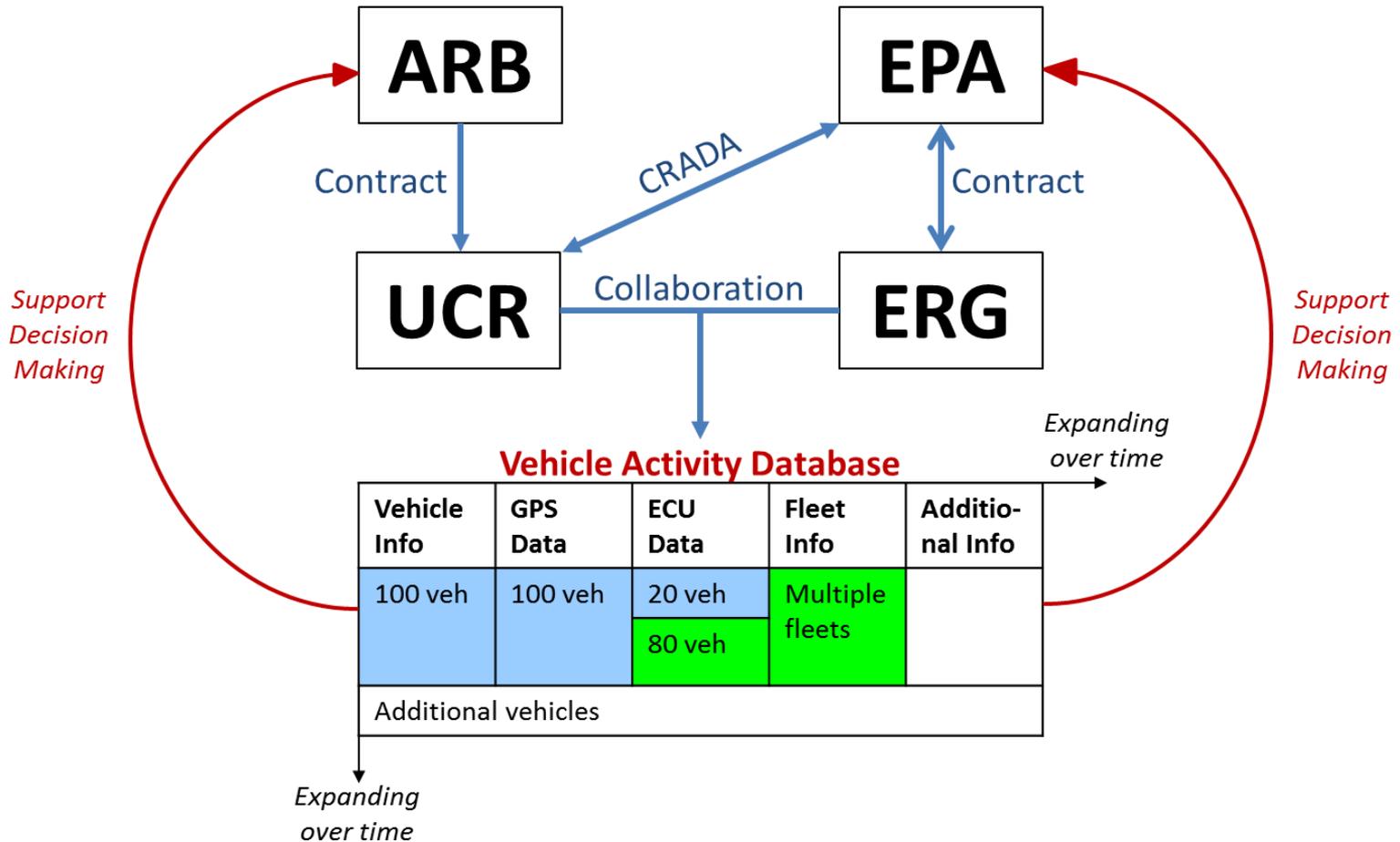


Project Objectives

- Collect real-world vehicle and engine activity data from HDVs in California.
 - Line haul, drayage, agriculture, construction, delivery, etc.
- Characterize HDV activity profiles by vocation.
 - Number of starts, idle time, soak period, etc.
- Identify fraction of vehicle operation that SCR may not be as effective for NO_x control.
 - Having low SCR temperature
- Develop vocation-specific drive cycles.
 - Possibly used for chassis dynamometer testing



Research Partnership





Data Collection

- Real-world vehicle and engine activity data from 90 trucks for a minimum of one month each.
 - GPS & ECU data loggers
 - 1 Hz data frequency
 - 170+ engine parameters
- Vehicle and engine information
 - Vehicle make, model, year
 - Engine make, model, year
 - Emission control equipment
 - GVWR
 - Odometer
 - Etc.





Vehicle Samples by Vocation

No.	Vocation	No. of Vehicles			No. of Fleets	Region	Comment
		Tar-geted	Install ed	Com-pleted			
1a	Line haul - out of state	5	3	3	1	No. Cal.	-
1b	Line haul - in state	5	4	3	1	So. Cal.	1 WiFi logger lost
2a	Drayage - No. Cal.	5	4	1	1	No. Cal.	3 WiFi loggers lost
2b	Drayage - So. Cal.	5	7	5	1	So. Cal.	2 cellular loggers lost
3a	Agricultural - No. CV	5	2	0	1	No. Cal.	2 cellular loggers lost
3b	Agricultural - So. CV	5	8	8	1	So. Cal.	1 cellular logger removed
4a	Construction	5	6	6	3	Both	-
4b	Cement mixers	5	5	5	2	Both	-
5a	Food distribution	5	5	5	1	So. Cal.	1 cellular logger lost
5b	Beverage distribution	5	10	6	1	So. Cal.	4 WiFi loggers lost
5c	Local moving	5	1	1	1	So. Cal.	-
6	Airport shuttle	5	5	5	1	No. Cal.	-
7	Refuse	5	6	6	1	No. Cal.	-
8a	Urban buses	5	6	6	1	No. Cal.	-
8b	Express buses	5	5	5	1	So. Cal.	-
9a	Freeway work	5	5	5	1	Both	-
9b	Sweeping	5	5	5	1	Both	-
9c	Municipal work	5	3	3	1	So. Cal.	-
9d	Towing	5	7	7	2	Both	-
10	Utility repair	5	5	5	1	No. Cal.	-
	Total	100	102	90	24	-	-

Notes: No. Cal. = Northern California; So. Cal. = Southern California; CV = Central Valley



Example Vehicles (1)



Line haul – out of state



Line haul – in state



Drayage – Southern California



Agricultural



Construction



Cement mixers 8



Example Vehicles (2)



Food distribution



Beverage distribution



Local moving



Airport shuttle



Refuse



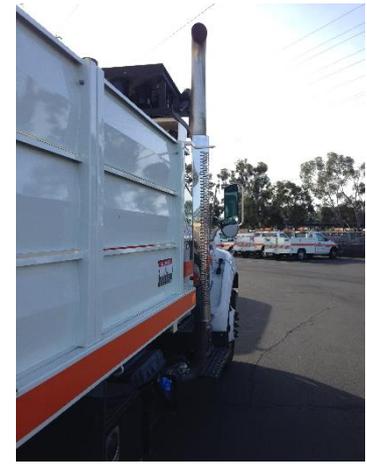
Urban buses
(diesel hybrid electric)



Example Vehicles (3)



Express buses
(CNG)



Freeway work



Sweeping



Municipal work



Towing



Utility repair



Data Processing

1. Data conversion
 - Converted and time-aligned GPS and ECU binary files into CSV file.
2. Map matching
 - Identified road type the vehicle was on for each data point.
3. Data quality assurance
4. Trip identification
5. Trip origin and destination cloaking
 - Removed latitude & longitude from first and last miles of each trip.
6. Data aggregation
 - Concatenated individual data files for each vehicle into a single file.



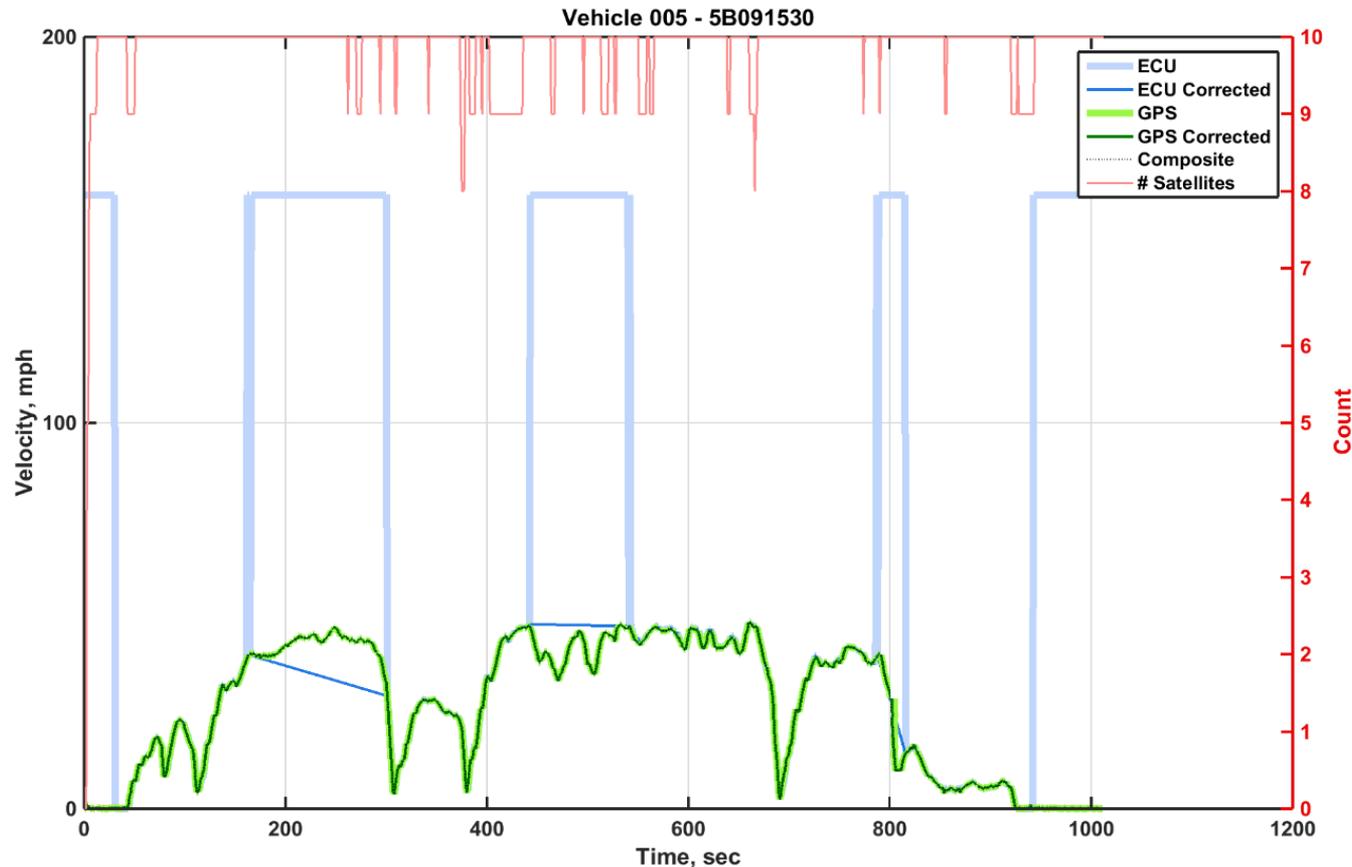
Data Quality Assurance

- Timestamp correction
 - GPS timestamp as primary source
 - Timestamp from data logger internal clock as secondary source
- Vehicle speed correction
 - GPS-based speed as primary
 - ECU-reported wheel-based speed as secondary
 - Vehicle speed data from GPS and ECU were corrected.
 - For each second, either corrected GPS or corrected ECU vehicle speed data were chosen depending on no. of satellites, speed level, etc.
 - Final result is *composite* vehicle speed data.



ECU-based Speed Data Issue – Ex. 1

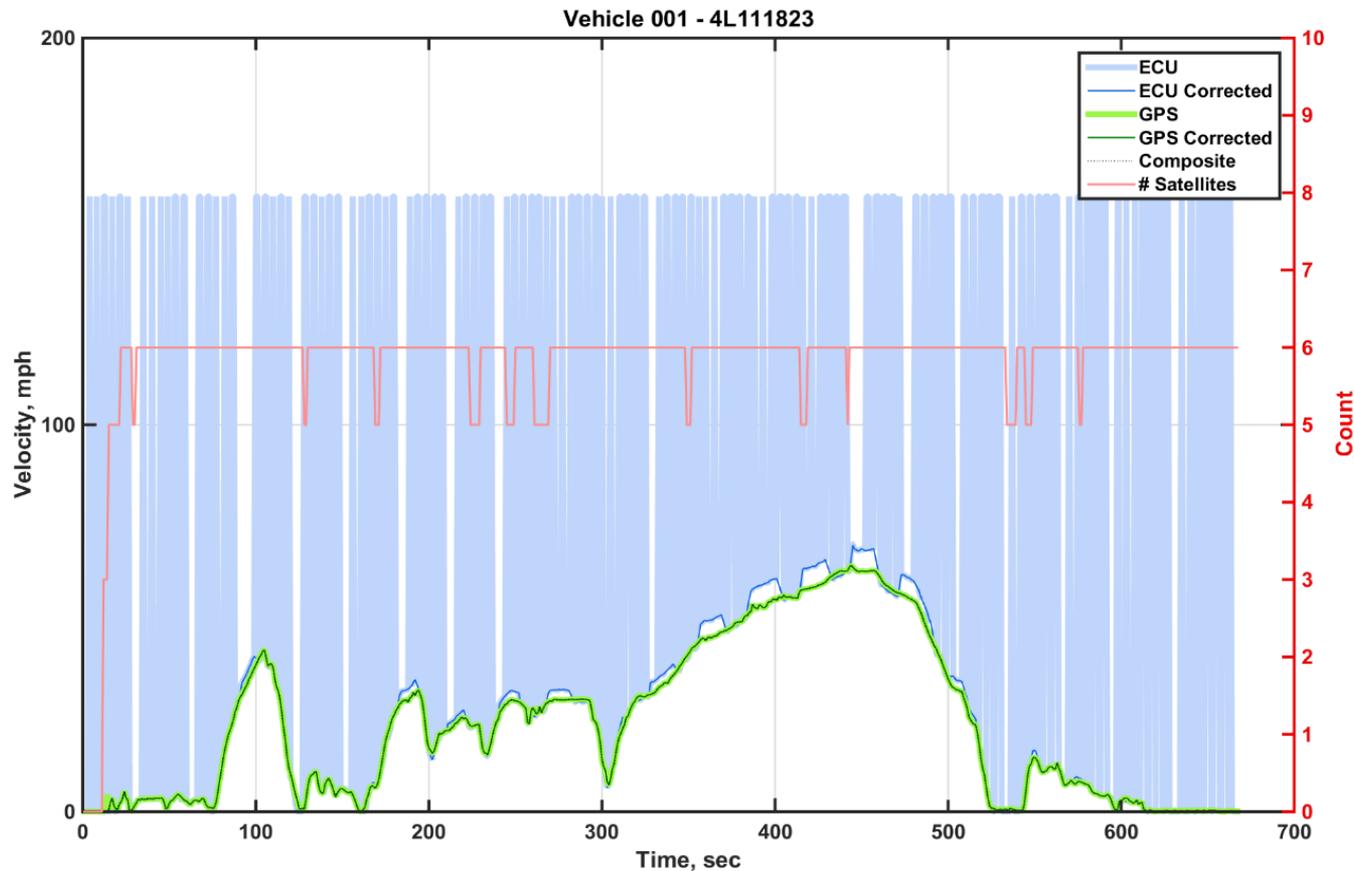
- Questionable ECU-based speed data with periods of unrealistically high values





ECU-based Speed Data Issue – Ex. 2

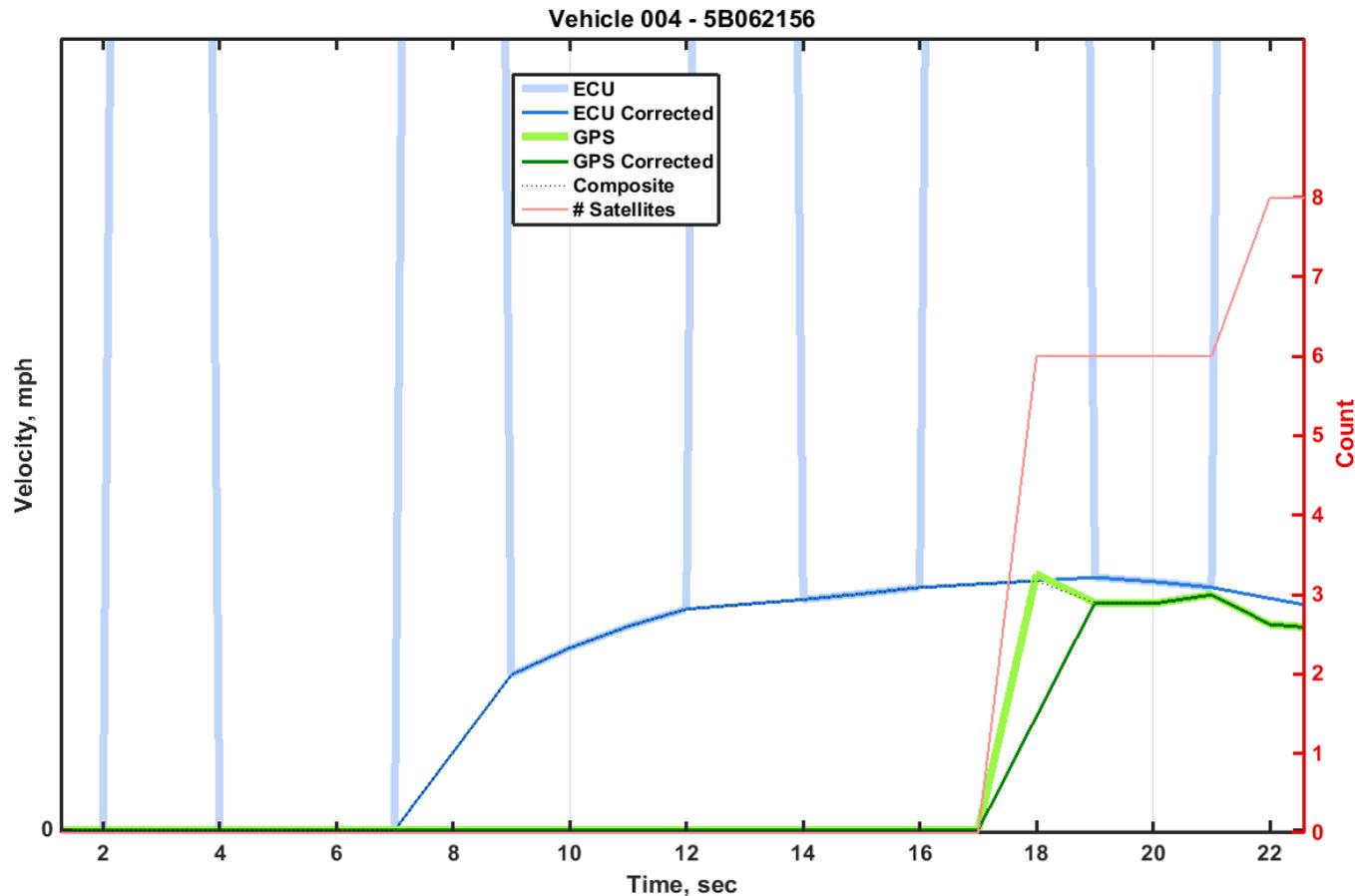
- Questionable ECU-based speed data with sporadic offsets





GPS-based Speed Data Issue

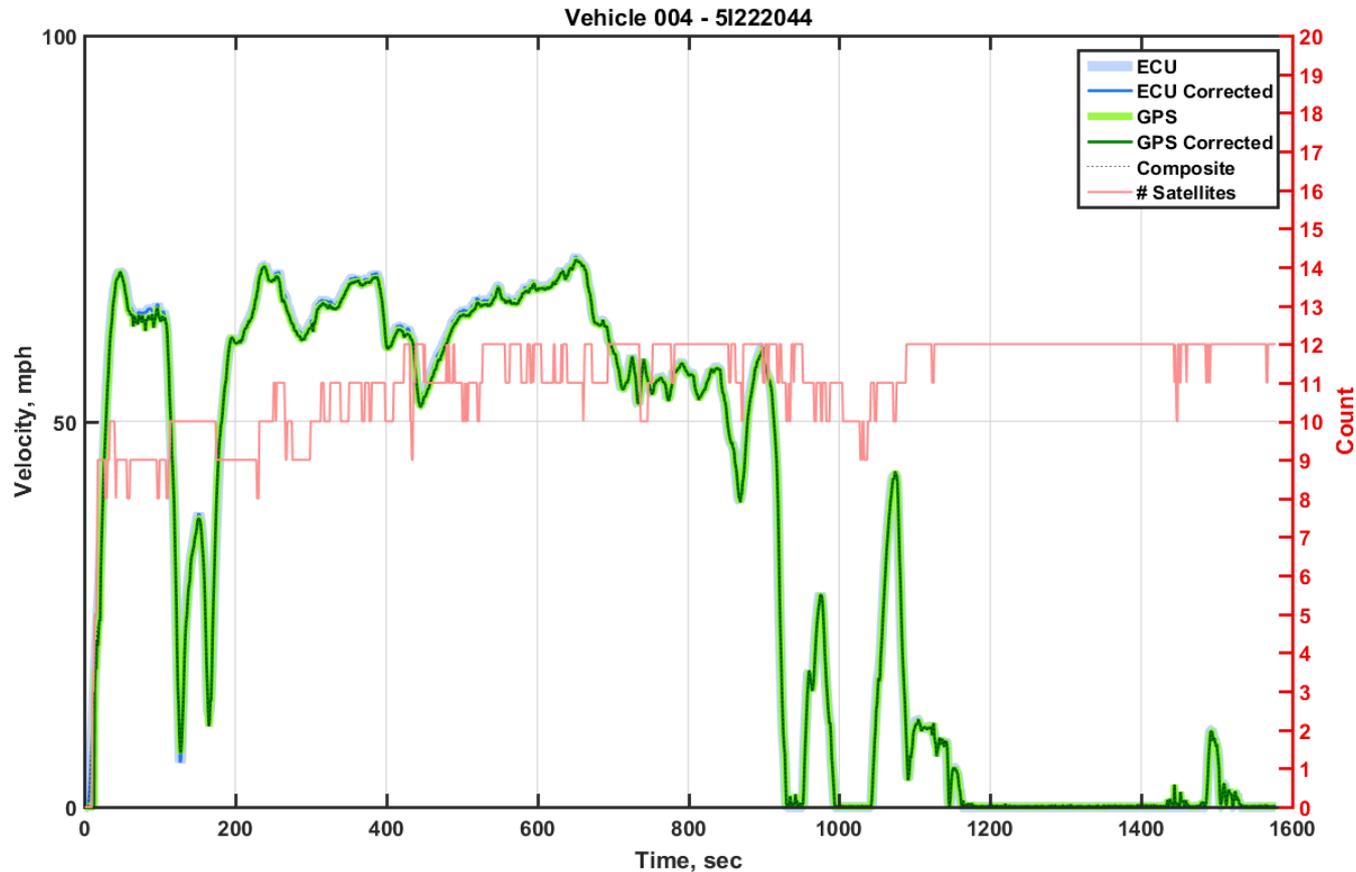
- Questionable GPS-based speed with low no. of satellites





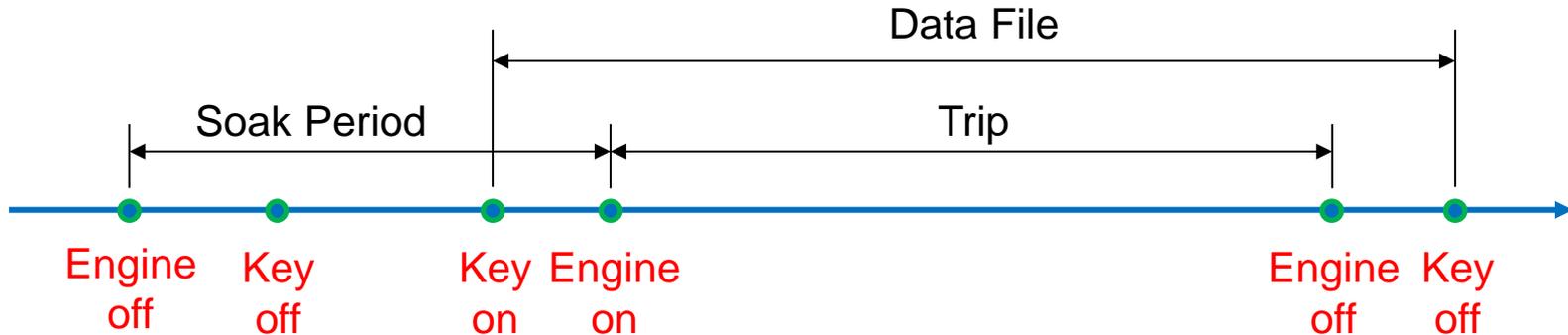
Composite Vehicle Speed

- Good match between GPS- and ECU-based speed data





Trip Identification

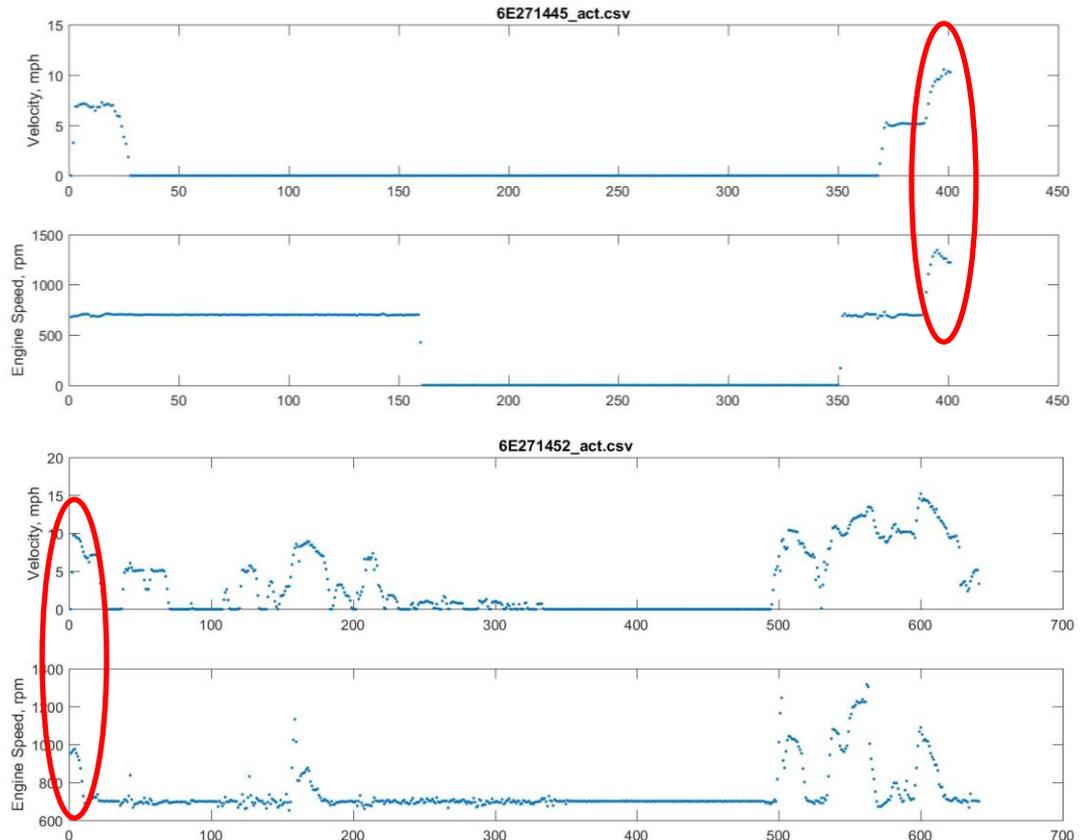


- A data file:
 - Is created when the key is switched on, powering up the logger.
 - Is ended when the key is switched off, powering down the logger.
 - Has no trip if key on is followed by key off.
 - Has multiple trips if engine off is followed by engine on.
- Engine on when $RPM > 300$
- Unique Trip ID was assigned to each trip.



Data File Merging

- Some data files were incorrectly created due to interruption of data connection with ECU.
 - Where the last RPM of a data file > 300 and the first RPM of the next data file > 300, the two data files were merged into a single data file before the trip identification was performed.



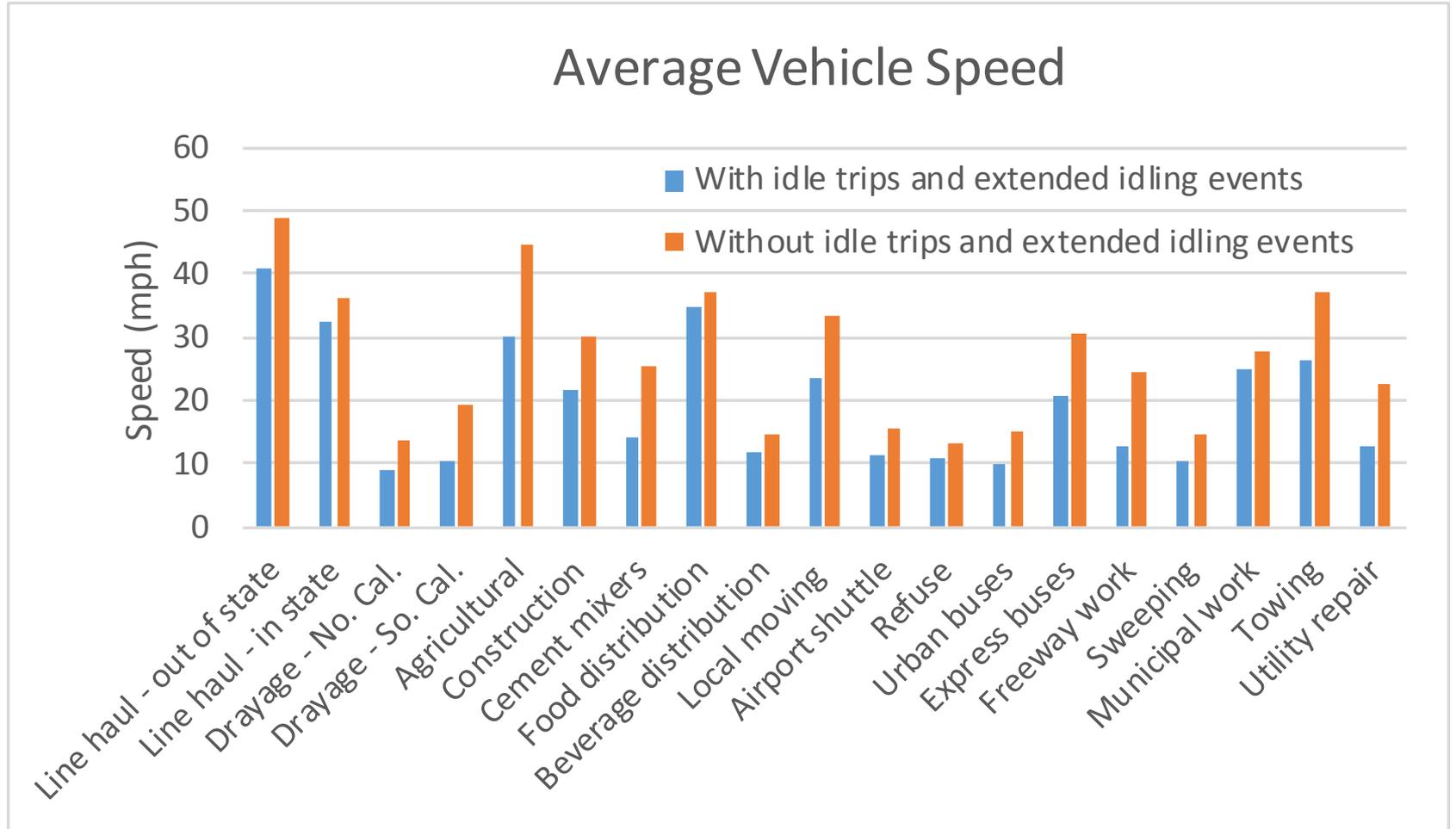


Vehicle Activity Analysis

- Used only weekday data for analysis
 - In line with EMFAC
- “Idle trip”
 - Trip speed < 5 mph
 - Trip distance < 5 mph
- “Extended idling event”
 - A continuous activity segment within a trip
 - Second-by-second vehicle speed < 5 mph
 - Total duration > 5 minutes
 - Total distance < 1 mile
- Calendar days vs. operation days



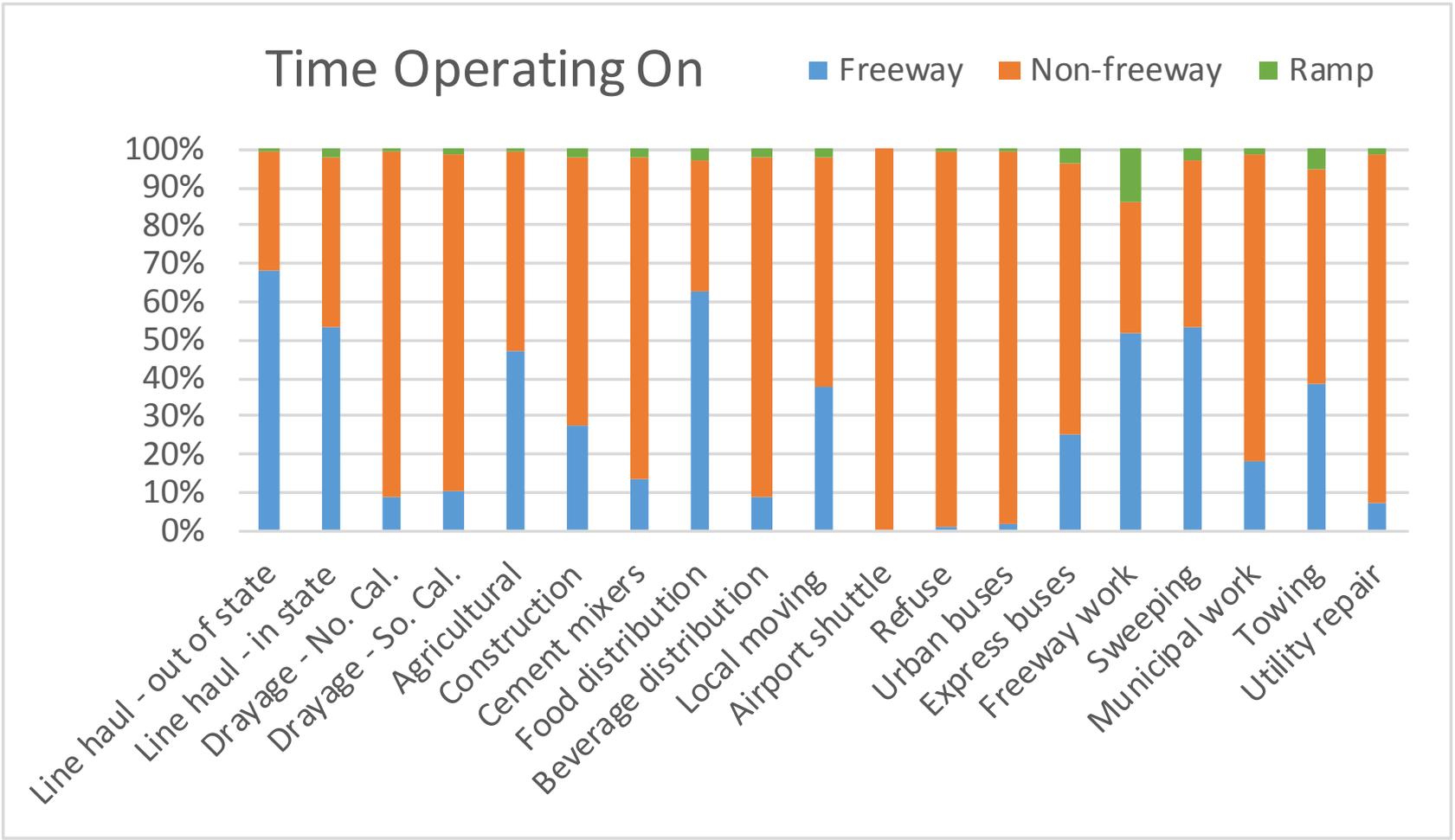
Average Vehicle Speed





Operating Time* by Road Type

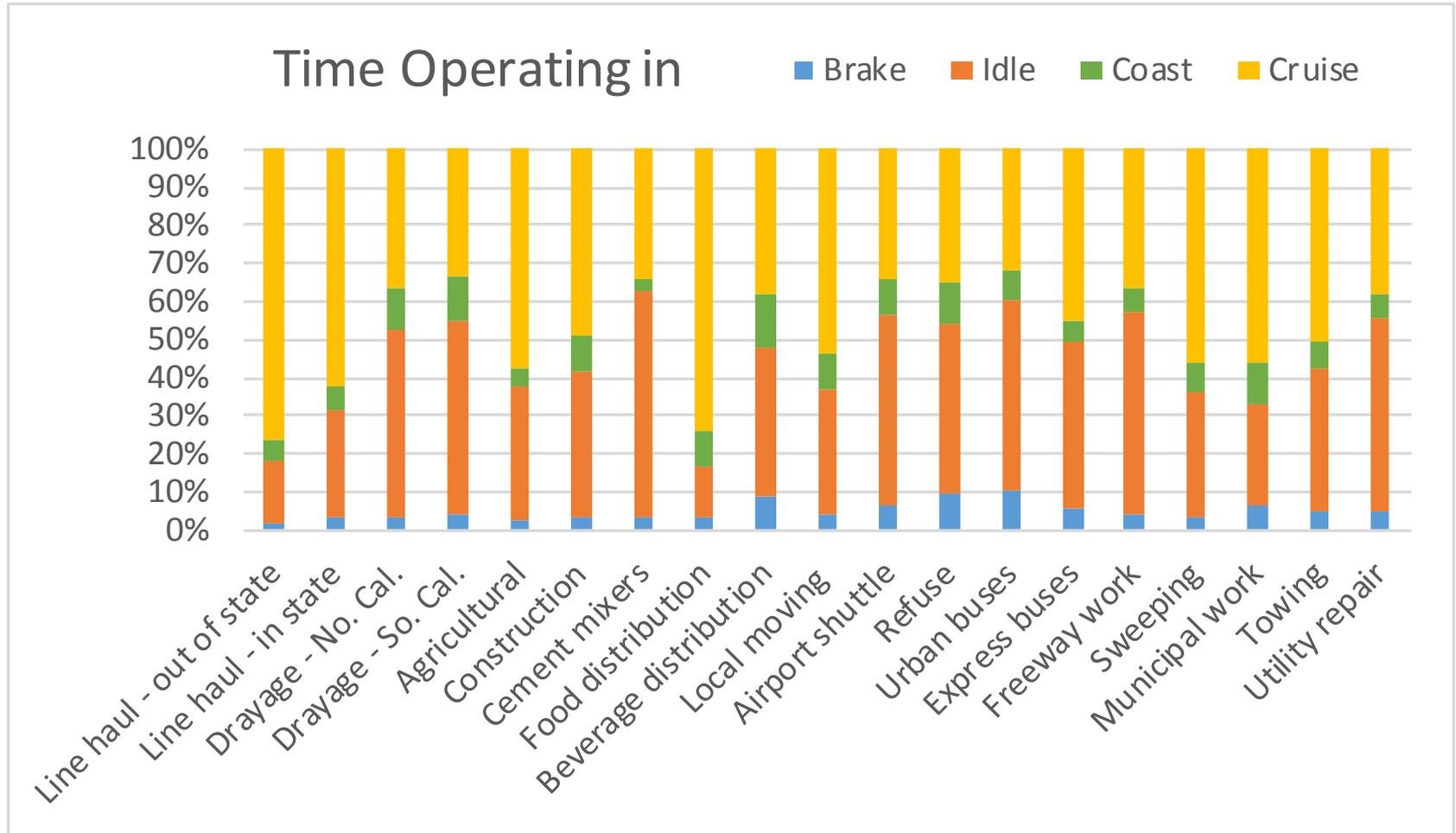
(*Including time during idle trips and extended idling events)





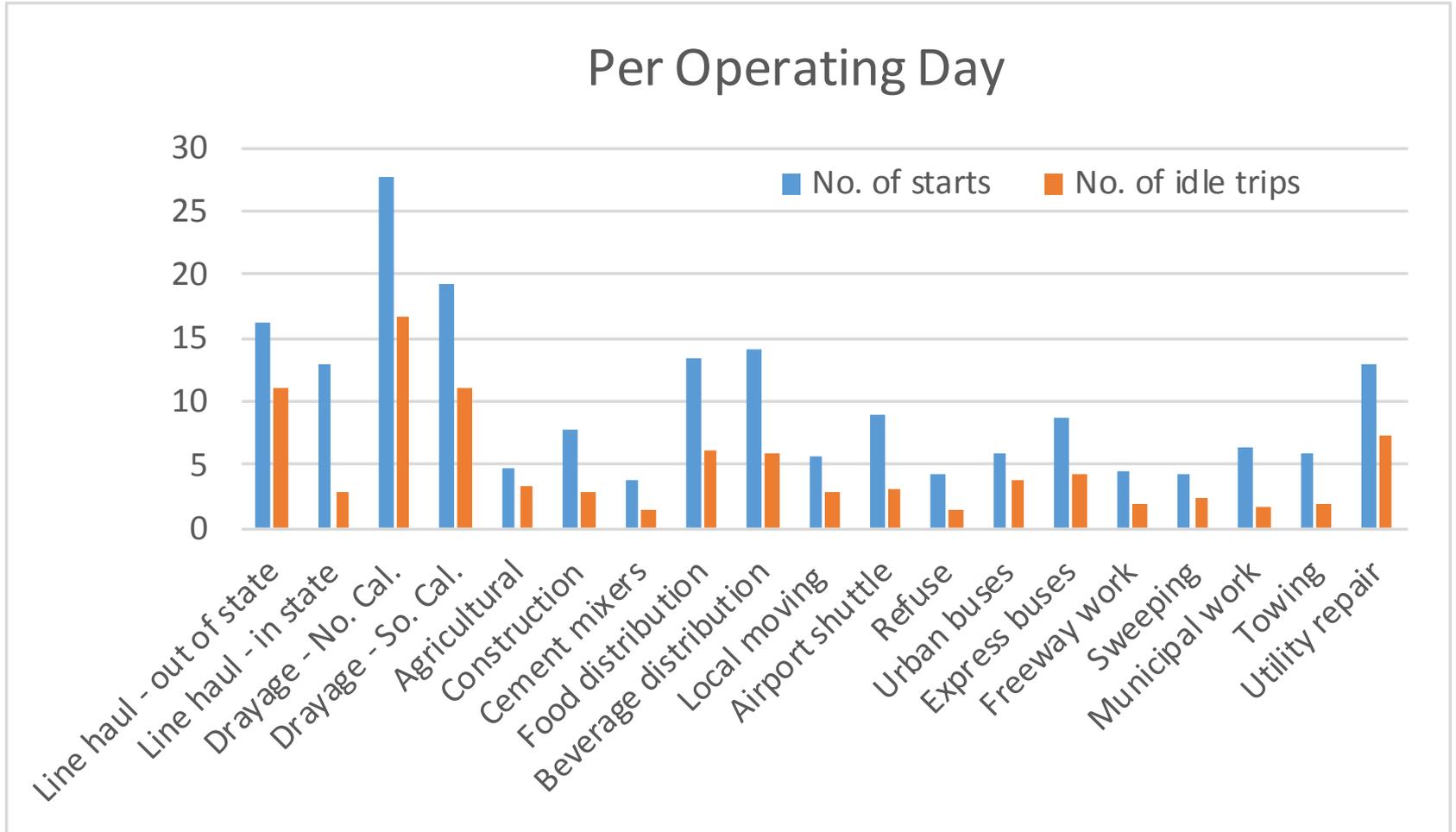
Operating Time* by Mode

(*Including time during idle trips and extended idling events)





No. of Starts and Idle Trips





Speed Dist. of NoCal Drayage Trucks

- Mostly daytime operation at low speeds.

Speed Bin	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	Sum	
	8.07	18.88	15.82	9.96	9.92	13.28	11.47	5.34	1.79	1.64	2.29	0.68	0.85	0	0	0	0	0	100	
Hour																				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.09	0.03	0.03	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	0.01	0.01	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	9.45	1.38	2.39	1.40	0.76	0.93	1.26	0.94	0.35	0.05	0	0	0	0	0	0	0	0	0	
8	8.40	0.76	2.08	1.84	0.94	0.71	0.90	0.81	0.33	0.05	0	0	0	0	0	0	0	0	0	
9	12.09	0.78	1.98	1.75	1.04	1.22	1.58	1.38	0.63	0.26	0.35	0.94	0.17	0.00	0	0	0	0	0	
10	12.16	0.75	1.97	1.73	1.02	1.21	1.43	1.22	0.92	0.50	0.34	0.48	0.14	0.45	0	0	0	0	0	
11	10.21	0.88	1.98	1.65	1.13	1.15	1.56	1.18	0.58	0.09	0.00	0	0	0	0	0	0	0	0	
12	5.54	0.49	1.01	0.84	0.68	0.67	0.90	0.71	0.21	0.03	0	0	0	0	0	0	0	0	0	
13	8.91	0.88	1.87	1.55	0.93	0.73	0.95	0.88	0.36	0.17	0.25	0.22	0.10	0	0	0	0	0	0	
14	11.74	0.76	2.01	1.65	1.06	1.11	1.64	1.73	0.66	0.29	0.46	0.32	0.04	0	0	0	0	0	0	
15	11.00	0.70	1.88	1.64	1.06	0.93	1.59	1.39	0.50	0.14	0.22	0.33	0.23	0.40	0	0	0	0	0	
16	9.01	0.53	1.43	1.53	1.16	1.09	1.27	1.01	0.77	0.21	0.02	0	0	0	0	0	0	0	0	
17	1.36	0.11	0.24	0.23	0.17	0.18	0.20	0.20	0.03	0.00	0	0	0	0	0	0	0	0	0	
18	0.04	0.01	0.01	0.00	0.00	0.00	0.01	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	100																			100



Spatial Dist. of NoCal Drayage Trucks





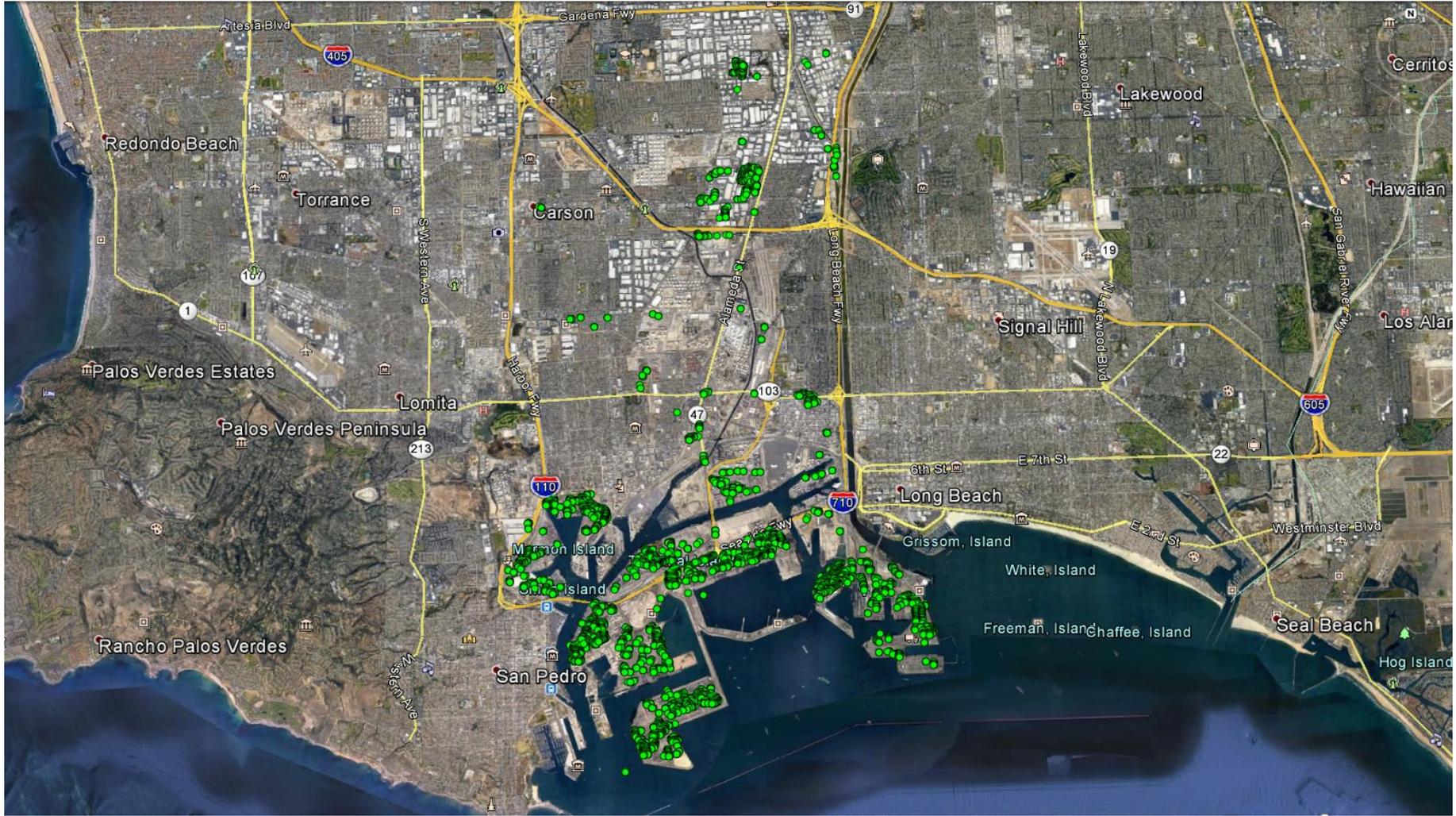
Speed Dist. of SoCal Drayage Trucks

- Both daytime and nighttime operation at higher speeds.

Speed Bin	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	Sum
	2.41	6.65	7.12	6.17	5.87	6.84	8.56	10.62	11.46	12.34	11.46	7.57	2.89	0.06	0	0	0	0	100
Hour																			
0	6.52	0.18	0.50	0.52	0.42	0.39	0.42	0.49	0.66	0.74	0.73	0.75	0.50	0.22	0.00	0	0	0	0
1	6.20	0.17	0.51	0.55	0.46	0.40	0.43	0.49	0.58	0.72	0.77	0.64	0.38	0.11	0.00	0	0	0	0
2	6.18	0.12	0.35	0.42	0.39	0.41	0.52	0.62	0.78	0.90	0.81	0.53	0.29	0.05	0	0	0	0	0
3	2.41	0.03	0.09	0.13	0.11	0.13	0.17	0.24	0.37	0.46	0.34	0.20	0.12	0.03	0	0	0	0	0
4	0.40	0.01	0.01	0.02	0.02	0.05	0.03	0.05	0.07	0.08	0.03	0.01	0.00	0	0	0	0	0	0
5	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	2.77	0.05	0.15	0.12	0.12	0.16	0.24	0.33	0.39	0.44	0.35	0.27	0.12	0.03	0	0	0	0	0
7	4.19	0.09	0.25	0.26	0.27	0.32	0.38	0.54	0.68	0.55	0.41	0.25	0.17	0.03	0	0	0	0	0
8	3.62	0.08	0.23	0.33	0.28	0.23	0.23	0.31	0.34	0.33	0.39	0.48	0.33	0.06	0	0	0	0	0
9	3.42	0.07	0.21	0.24	0.22	0.20	0.24	0.30	0.38	0.37	0.39	0.31	0.29	0.21	0.00	0	0	0	0
10	4.32	0.07	0.20	0.22	0.20	0.21	0.23	0.30	0.42	0.41	0.57	0.72	0.45	0.30	0.01	0	0	0	0
11	3.30	0.07	0.18	0.20	0.19	0.20	0.28	0.35	0.34	0.30	0.35	0.40	0.32	0.10	0.00	0	0	0	0
12	3.26	0.05	0.14	0.16	0.16	0.20	0.26	0.31	0.34	0.31	0.42	0.33	0.37	0.21	0.00	0	0	0	0
13	2.97	0.06	0.18	0.21	0.19	0.20	0.23	0.26	0.27	0.25	0.33	0.39	0.31	0.08	0	0	0	0	0
14	2.99	0.06	0.18	0.21	0.18	0.18	0.21	0.22	0.26	0.28	0.28	0.39	0.31	0.20	0.02	0	0	0	0
15	3.28	0.05	0.18	0.24	0.23	0.23	0.24	0.34	0.41	0.41	0.47	0.35	0.12	0.00	0	0	0	0	0
16	1.79	0.04	0.13	0.14	0.15	0.14	0.18	0.20	0.26	0.23	0.18	0.10	0.03	0.00	0	0	0	0	0
17	3.50	0.12	0.30	0.25	0.22	0.25	0.31	0.38	0.47	0.45	0.37	0.26	0.10	0.02	0.00	0	0	0	0
18	6.15	0.21	0.52	0.55	0.46	0.43	0.52	0.67	0.77	0.72	0.56	0.46	0.25	0.03	0	0	0	0	0
19	5.55	0.21	0.49	0.52	0.42	0.33	0.34	0.45	0.57	0.71	0.75	0.53	0.20	0.02	0	0	0	0	0
20	6.12	0.21	0.52	0.50	0.39	0.30	0.32	0.36	0.53	0.84	0.95	0.80	0.35	0.04	0	0	0	0	0
21	8.34	0.20	0.50	0.53	0.46	0.41	0.46	0.58	0.71	0.82	1.30	1.50	0.68	0.17	0.00	0	0	0	0
22	6.46	0.13	0.37	0.34	0.29	0.27	0.32	0.44	0.62	0.73	0.82	0.87	0.94	0.32	0.00	0	0	0	0
23	6.24	0.15	0.44	0.43	0.34	0.25	0.25	0.35	0.40	0.42	0.71	0.89	0.92	0.65	0.02	0	0	0	0
Sum	100																		100



Spatial Dist. of SoCal Drayage Trucks





Full-Day vs. Part-Day Operation

Full-Day Operation	Part-Day Operation
Line haul – in state	Line haul – out of state
Drayage – Southern California	Drayage – Northern California
Agricultural	Construction
Shuttle	Cement mixers
Towing	Food distribution
Utility repair	Beverage distribution
	Local moving
	Refuse
	Urban buses
	Express buses
	Freeway work
	Sweeping
	Municipal work



Soak Dist. of Municipal Work Trucks

- Short soaks (< 2 hours) throughout operation hours with long (> 12 hours) overnight soaks.

Soak Period	5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	Sum	
	25.18	11.38	15.74	10.41	7.51	3.87	2.91	5.33	0.97	0.48	0.73	0	0	0	0	0	0	0	15.50	100	
Hour																					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.97	0
6	12.83	2.18	0.24	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.17	0
7	11.38	1.69	2.42	1.94	0.97	0.73	0.48	0.48	0	0	0	0	0	0	0	0	0	0	0	2.66	0
8	8.23	1.94	1.21	0.97	0.24	0.97	0.48	0.73	1.21	0	0	0	0	0	0	0	0	0	0	0.48	0
9	13.80	3.63	2.18	2.42	2.66	1.21	0.24	0.24	0.48	0.24	0	0	0	0	0	0	0	0	0	0.48	0
10	6.05	1.94	0.97	0.97	0.48	0.24	0.24	0	0.97	0	0	0	0	0	0	0	0	0	0	0.24	0
11	8.72	3.39	0.48	1.94	1.21	0.97	0.48	0	0.24	0	0	0	0	0	0	0	0	0	0	0	0
12	9.93	1.69	0.73	1.94	1.45	1.45	0.24	0.97	0.73	0	0.24	0	0	0	0	0	0	0	0	0.48	0
13	6.30	2.66	0.48	1.45	0.24	0.24	0.24	0	0.24	0.24	0.24	0	0	0	0	0	0	0	0	0	0
14	9.93	2.18	1.69	1.45	0.97	1.21	0.97	0.48	0.24	0.48	0	0.24	0	0	0	0	0	0	0	0	0
15	9.44	2.91	1.21	1.45	1.69	0.48	0.48	0	0.97	0	0.24	0	0	0	0	0	0	0	0	0	0
16	2.18	0.97	0	0.97	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.24	0	0	0	0	0	0	0	0.24	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	100																			15.50	100



Soak Dist. of Beverage Dist. Trucks

- Sporadic soak periods throughout the day with the most common being 10-20 minutes in late morning.

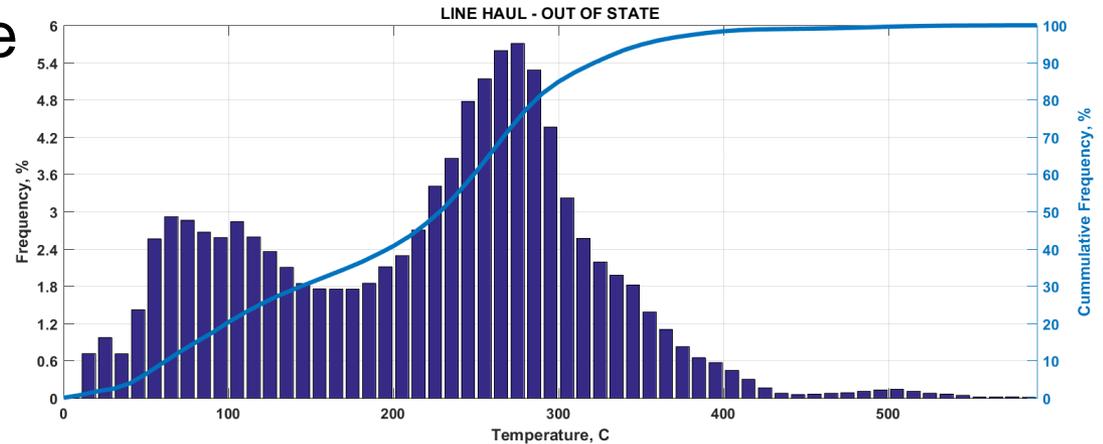
Soak Period	5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	Sum	
	12.34	10.01	16.83	11.60	9.48	7.00	5.08	13.52	2.92	1.51	0.83	0.77	0.83	0.65	0.92	0.89	0.86	0.71	3.28	100	
Hour																					
0	0.94	0.03	0.03	0.15	0	0.12	0.06	0	0	0	0	0	0.06	0	0.18	0.06	0.03	0.03	0.21		
1	1.24	0.06	0.06	0.06	0.03	0.09	0	0.12	0.38	0.03	0	0	0	0.03	0.12	0.03	0.06	0	0.18		
2	0.74	0	0	0.03	0.06	0.09	0.03	0.06	0.09	0	0	0.03	0	0.03	0	0.03	0.09	0.09	0.12		
3	1.71	0.09	0	0.12	0.09	0.15	0.09	0.09	0.32	0.09	0.18	0.03	0	0.03	0	0.09	0.06	0.06	0.24		
4	2.80	0.32	0.32	0.53	0.30	0.18	0.09	0.06	0.15	0.24	0.09	0.09	0.03	0.06	0.15	0	0	0.09	0.12		
5	3.28	0.35	0.21	0.27	0.15	0.21	0.30	0.24	0.50	0.12	0.03	0.06	0.06	0	0.09	0.09	0.06	0.09	0.15	0.32	
6	9.09	2.18	1.03	1.00	0.30	0.30	0.24	0.24	0.62	0.41	0.18	0.09	0.15	0.09	0.12	0.35	0.44	0.41	0.24	0.71	
7	6.05	1.18	0.56	1.09	0.62	0.41	0.38	0.30	0.62	0.15	0	0	0	0.03	0.03	0.06	0.12	0.03	0.47		
8	7.53	0.68	0.77	1.62	0.92	0.80	0.71	0.41	1.39	0.15	0.03	0	0	0	0	0	0	0	0.06		
9	8.83	1.03	0.83	1.65	1.51	0.83	0.65	0.41	1.51	0.18	0.06	0	0	0	0.03	0	0	0	0.15		
10	8.83	0.89	0.68	1.80	1.42	1.09	0.77	0.41	1.36	0.21	0.12	0	0	0	0	0	0	0	0.09		
11	9.09	0.92	0.92	2.27	1.42	0.97	0.97	0.35	0.92	0.21	0.03	0	0	0	0	0	0	0	0.12		
12	8.33	0.94	0.86	1.62	1.33	1.09	0.56	0.53	1.15	0.18	0	0	0	0.03	0	0	0	0	0.03		
13	6.76	0.50	0.77	1.36	0.94	0.86	0.50	0.62	1.03	0.15	0	0	0	0.03	0	0	0	0	0	0	
14	6.88	0.74	0.80	1.06	1.21	0.71	0.65	0.32	1.21	0.15	0	0	0	0	0	0	0	0	0.03		
15	4.72	0.56	0.65	0.65	0.41	0.77	0.38	0.32	0.77	0.09	0.09	0	0	0	0	0	0	0	0.03		
16	4.58	0.83	0.74	0.86	0.44	0.32	0.15	0.18	0.71	0.09	0.15	0.03	0.03	0.03	0	0	0	0	0.03		
17	2.83	0.74	0.47	0.41	0.24	0.15	0.12	0.15	0.21	0.18	0.06	0.06	0.06	0	0	0	0	0	0	0	
18	1.27	0.18	0.32	0.09	0.09	0.06	0.03	0.09	0.09	0.09	0.09	0.06	0	0.06	0	0	0	0	0.03		
19	0.92	0.03	0	0.06	0	0.03	0.09	0.06	0.12	0.15	0.12	0.06	0.03	0.06	0	0.03	0	0	0.09		
20	1.09	0	0	0.03	0.03	0.09	0.09	0.06	0.12	0.03	0.18	0.15	0.15	0.12	0.03	0	0	0	0.03		
21	1.21	0.06	0	0.03	0.09	0.09	0.09	0.03	0.18	0.03	0.09	0.15	0.12	0.18	0.03	0	0	0	0.06		
22	0.50	0.03	0	0.03	0	0.03	0.03	0.06	0.03	0.03	0.03	0.06	0.06	0.03	0.03	0	0	0	0.06		
23	0.77	0	0	0.03	0.03	0.09	0.03	0	0.03	0	0	0	0	0.15	0.06	0.12	0	0.03	0.12		
Sum	100																			100	



SCR Temperature Dist. – Ex. 1

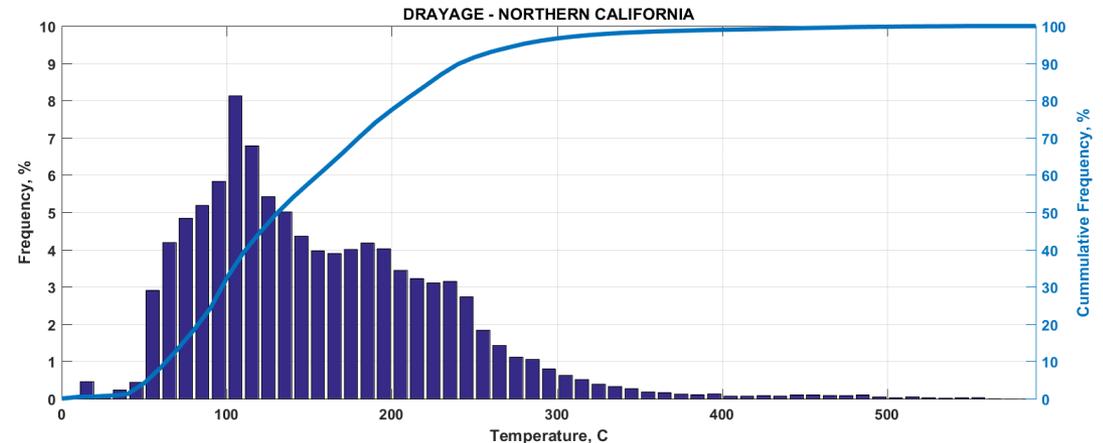
- Line haul - out of state

- Mode ~ 280 °C
- 39% time < 200 °C
- 56% time < 250 °C



- Drayage - No. Cal.

- Mode ~ 110 °C
- 74% time < 200 °C
- 90% time < 250 °C

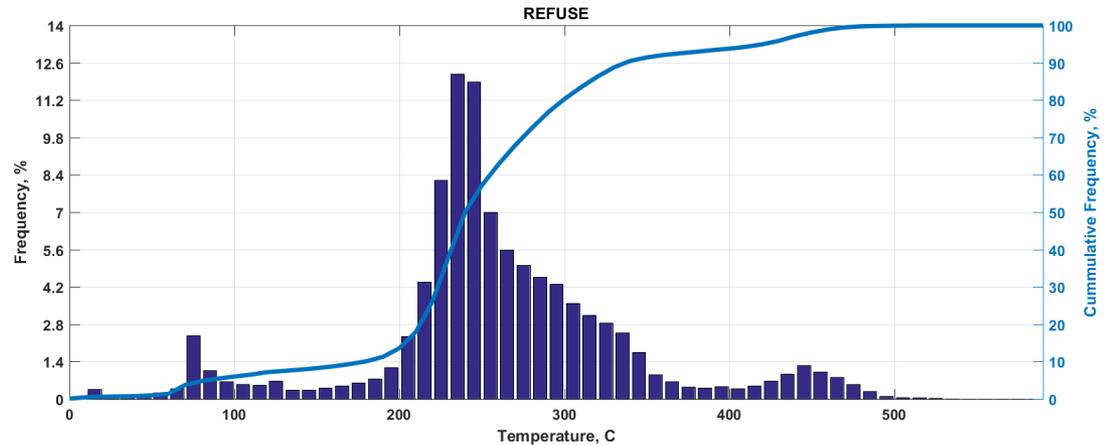




SCR Temperature Dist. – Ex. 2

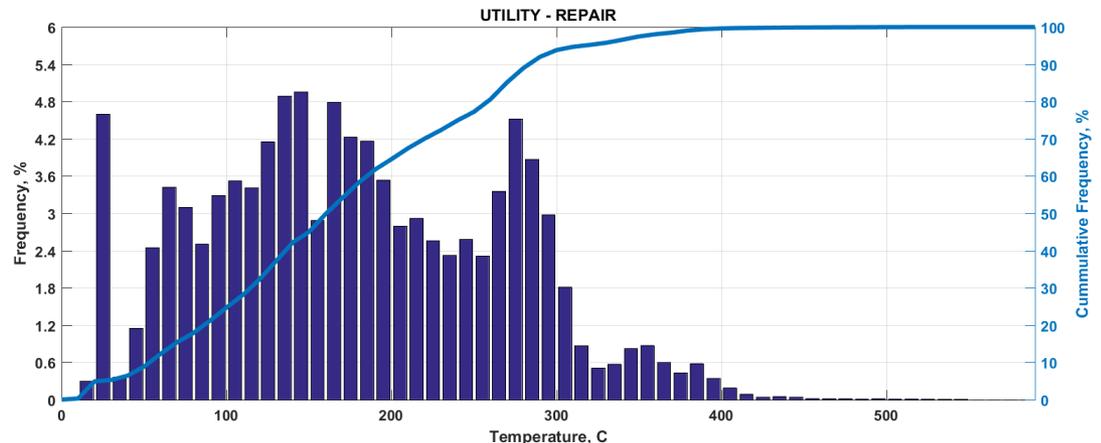
- Refuse

- Mode ~ 240 °C
- 11% time < 200 °C
- 50% time < 250 °C



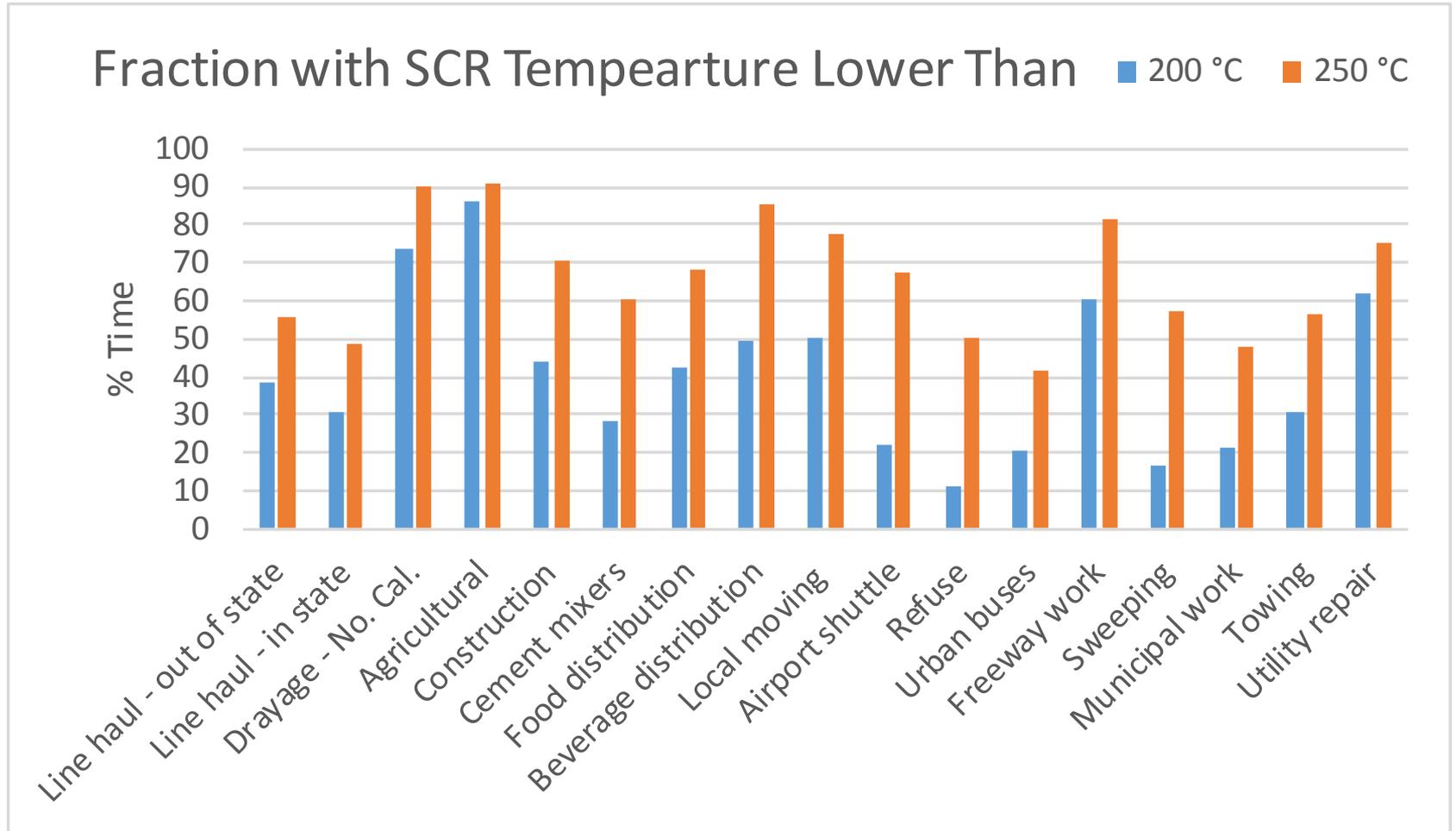
- Utility - repair

- Mode ~ 150 °C
- 62% time < 200 °C
- 75% time < 250 °C



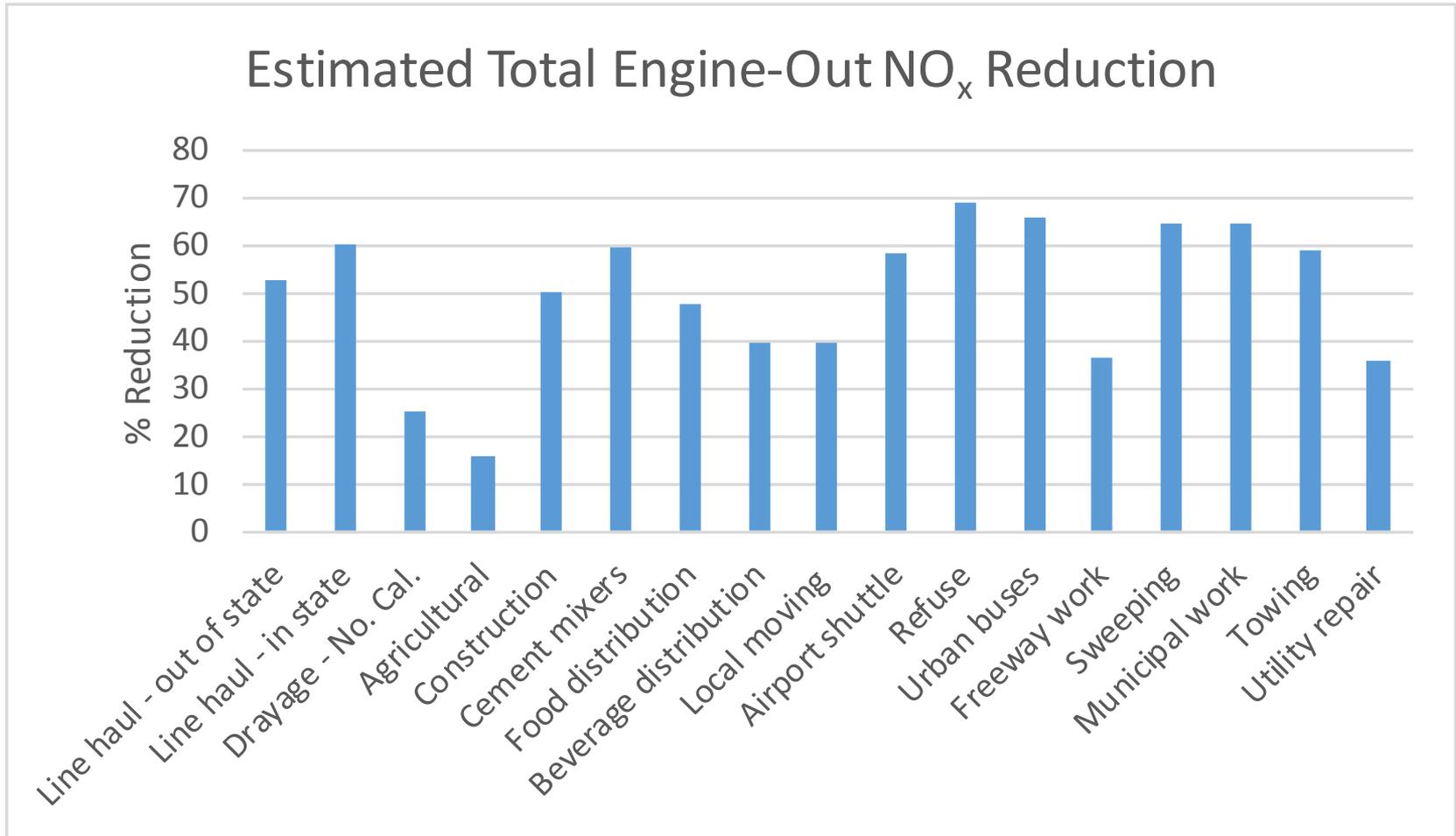


Fraction at Low SCR Temperature





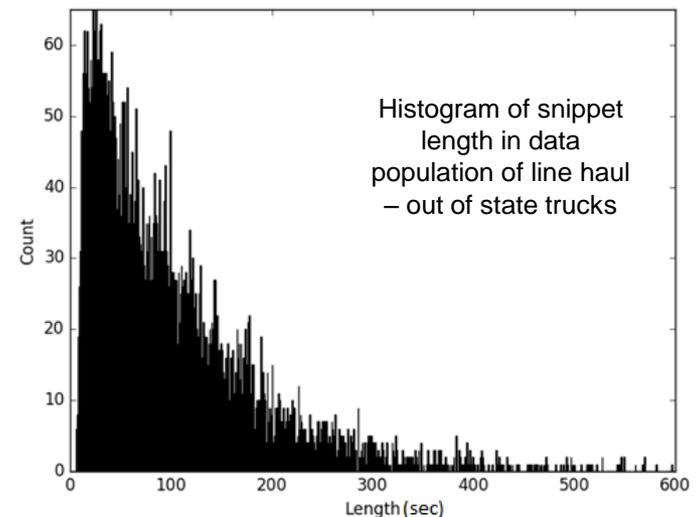
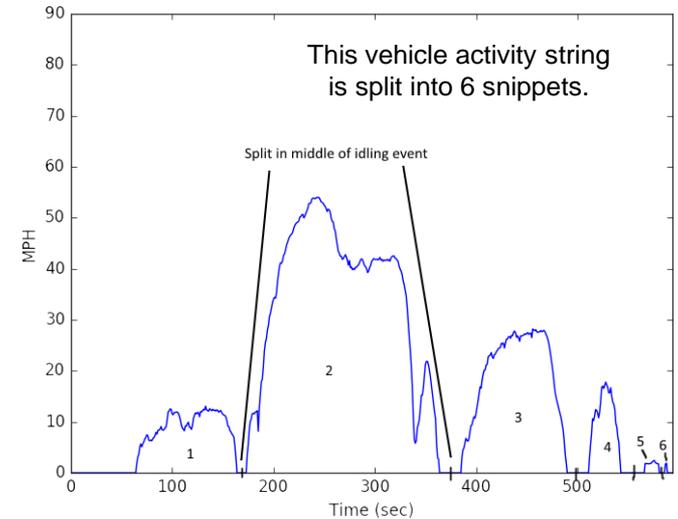
Estimated NO_x Reduction by SCR





Drive Cycle Development (1)

1. Data reduction
 - Removed extended idling events.
 - Trip → vehicle activity strings
2. Vehicle activity splitting
 - Split vehicle activity string in the middle of every idling event.
 - Vehicle activity string → snippets
3. Candidate cycle generation
 - Connected two or more snippets to generate a candidate cycle.
 - Each snippet is also a candidate cycle by itself.





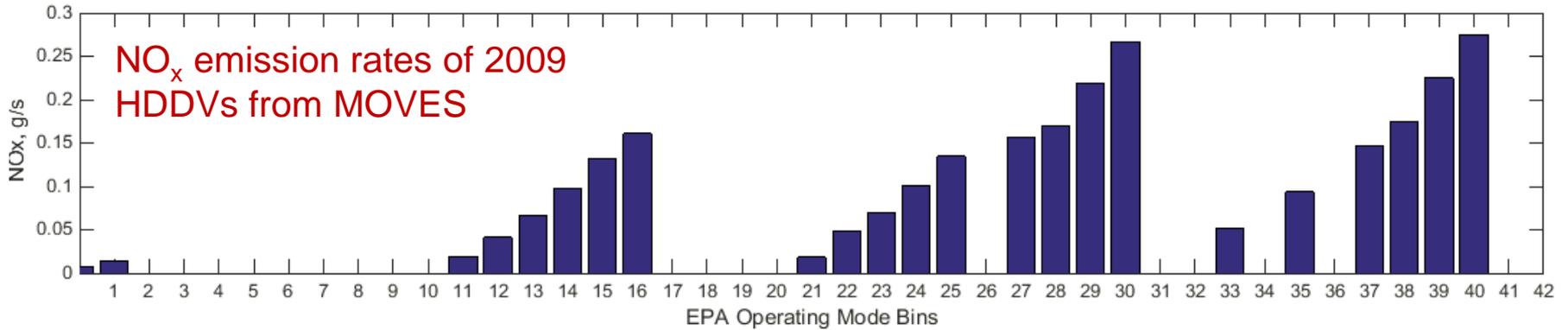
Drive Cycle Development (2)

4. Selection of representative cycle
 - Lowest mean squared error of operating mode distribution
 - Operating modes are used in EPA’s MOVES model to characterize emissions

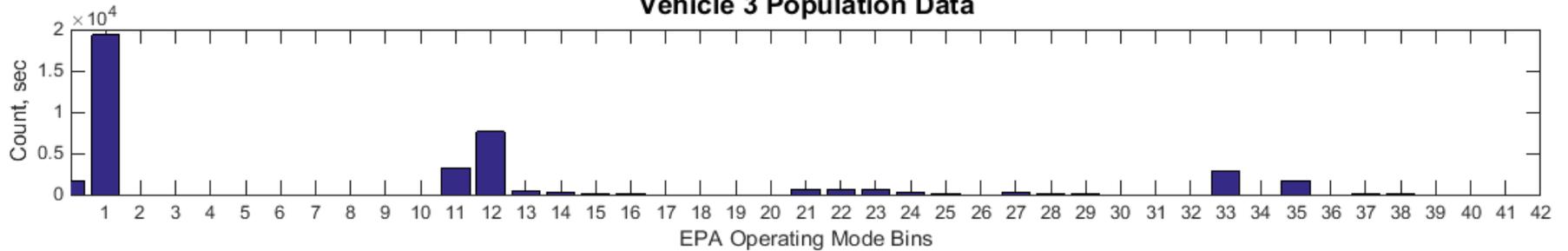
	Speed Class (mph)			
	1-25	25-50	50 +	
30 +	16	30	40	21 modes representing "cruise & acceleration" (VSP>0) PLUS 2 modes representing "coasting" (VSP<=0) PLUS One mode each for idle, and decel/braking ----- Gives a total of 23 opModes
27-30				
24-27		29	39	
21-24		28	38	
18-21				
15-18			37	
12-15		27		
9-12	15	25		
6-9	14	24	35	
3-6	13	23		
0-3	12	22	33	
< 0	11	21		



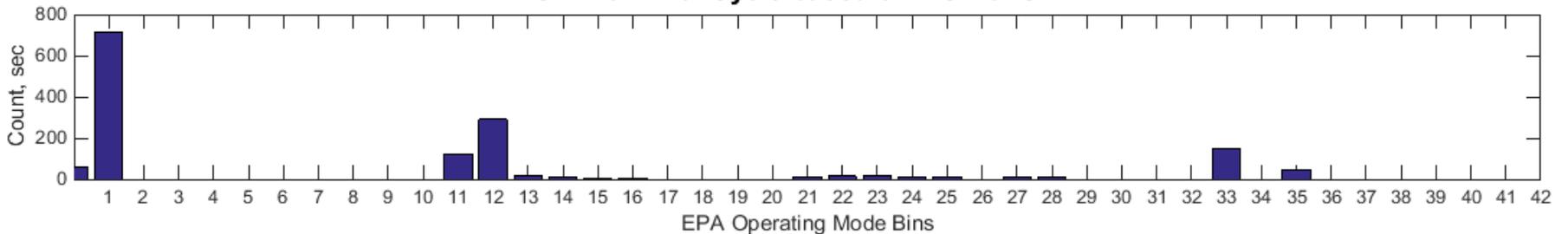
Operating Mode Distribution



Vehicle 3 Population Data



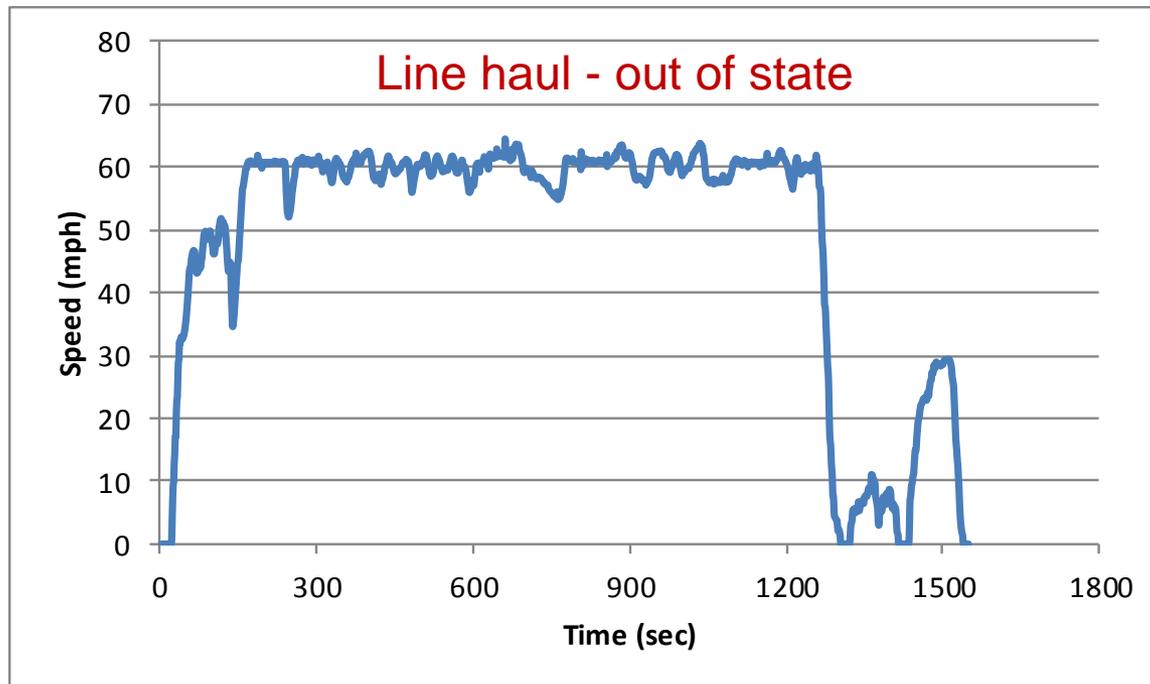
OMD of Final Cycle based on MSE of OMD





Drive Cycles – Mostly Highway Cruising

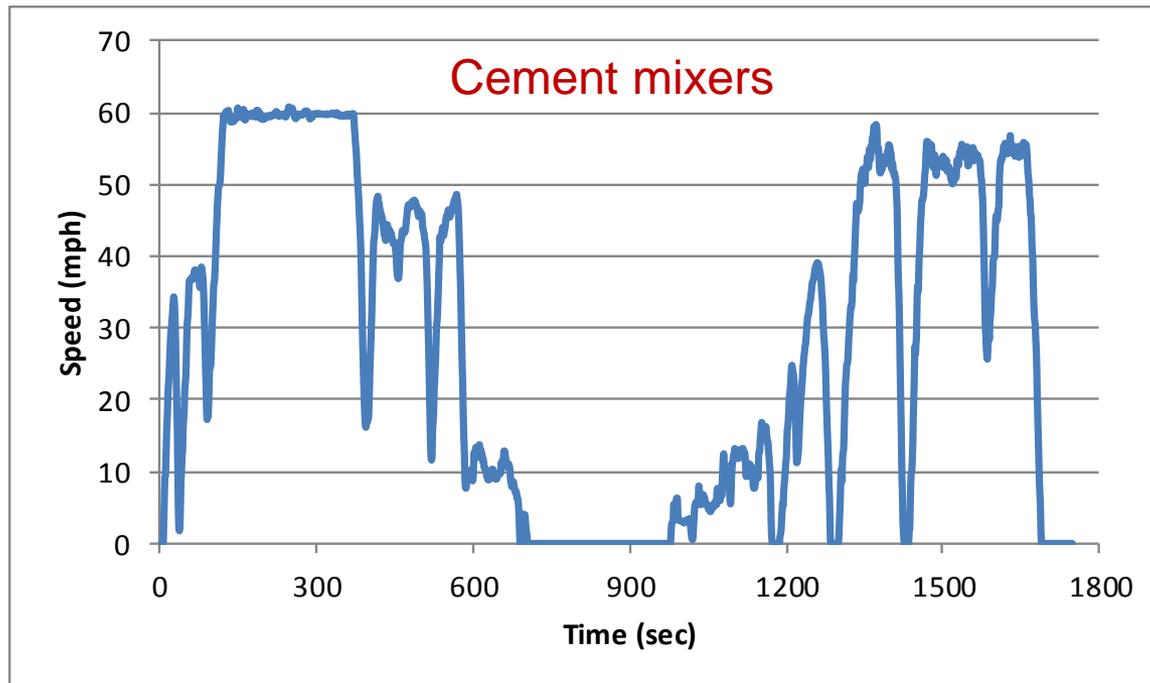
- Spend most of the time cruising at highway speeds
- Line haul - out of state, line haul - in state, and agricultural





Drive Cycles – Mixed Driving

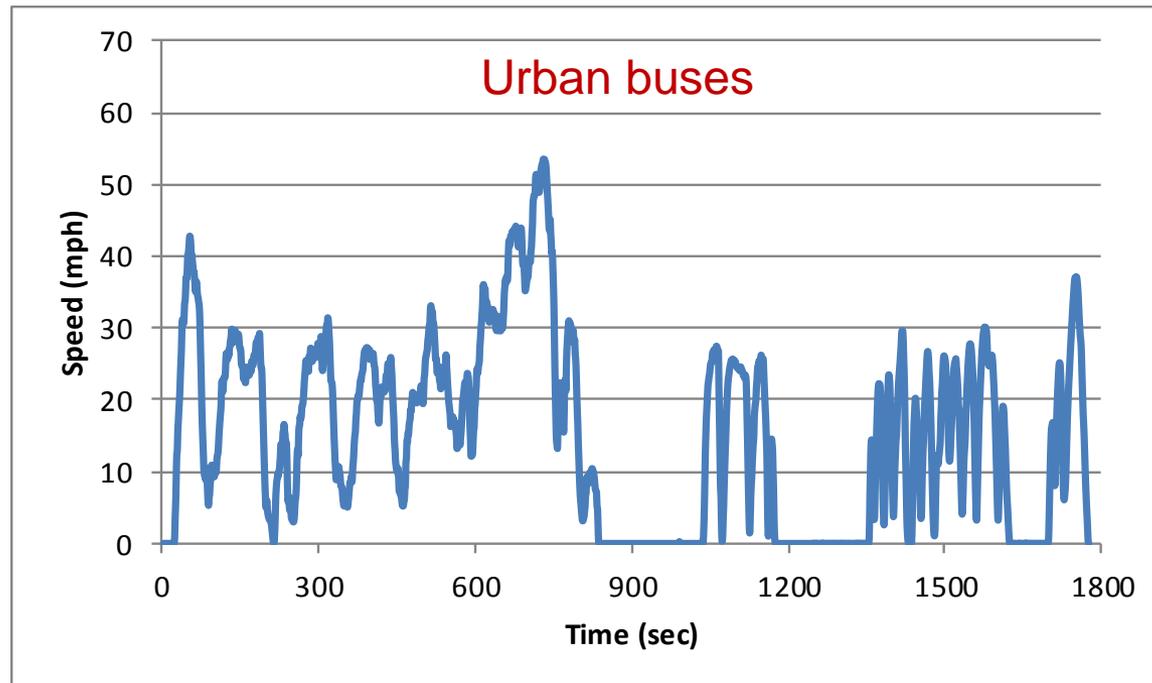
- Mix of freeway and non-freeway driving
- Construction, cement mixers, food distribution, local moving, express buses, freeway work, municipal work, and towing





Drive Cycles – Mostly Transient

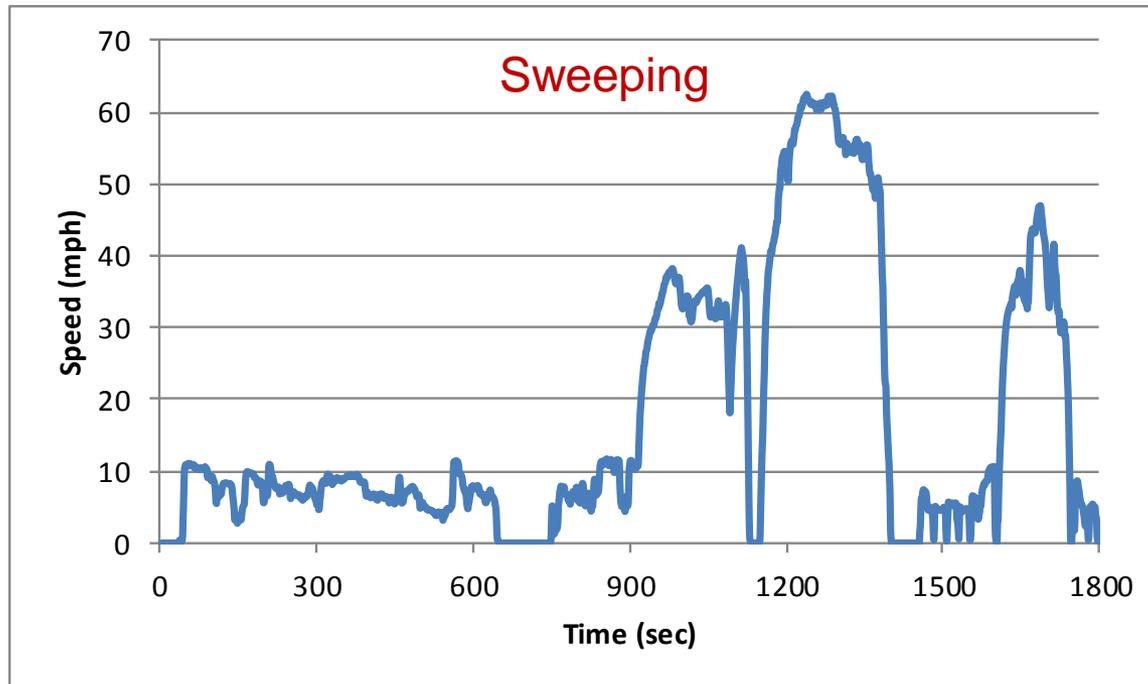
- Spend most of the time in transient mode
- Drayage, beverage distribution, airport shuttle, urban buses and utility - repair





Drive Cycles – Mostly Creeping

- Spend most of the time creeping at low speed
- Sweeping and refuse





Concluding Remarks (1)

- Vehicle and engine activity data were collected from 90 HDVs in a variety of vocations.
- The collected data were analyzed to reveal the vehicles' real-world activity and SCR temperature profiles by vocation.
- Results indicate that:
 - HDV activity patterns vary greatly by vocation, and in some cases, also by geographic area.
 - SCR temperature of HDVs in this study is lower than 200 °C for 11-87% of the time, depending on vocation.
 - Estimated engine-out NO_x reduction ranges from 16% to 69%, depending on vocation.



Concluding Remarks (2)

- The data were also used to develop vocation-specific drive cycles, which can be used for emission testing on chassis dynamometer.
- The data can be further analyzed to help answer questions related to in-use emissions from HDVs, e.g.,
 - Are the current approach to NO_x emission standards for heavy-duty diesel vehicles effective?
 - What are the most suitable alternative fuel/vehicle technologies for heavy-duty vehicles in different vocations?
 - What other emission control strategies or policies could be developed?



Recommendations for Future Research

- Collect data from additional vehicles and vocations.
- Analyze the effectiveness/impact of commercial vehicle idling regulation.
- Further characterize real-world SCR temperature profiles by other factors, e.g., engine make/model/year.
- Improve thermal management of SCR.
- Evaluate potential benefits of “geofencing” technology around disadvantaged communities.
- Determine feasibility of vehicle electrification for specific vocations.



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